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METHOD FOR ACTIVATING A TWO-STAGE SWITCHING VALVE

Background Information

The present invention relates to a method for activating a two-stage switching valve as recited in the preamble of Claim 1.

Modern vehicles having vehicle dynamics control systems such as an ESP (Electronic Stability Program) or TCS (Traction Control System) include specially adapted brake systems. Brake systems of this type usually have multiple valves which may be used to switch between a foot brake operating mode and an automatic brake operating mode.

Figure 1 shows a hydraulic brake system 14 known from the related art which is provided to carry out a vehicle dynamics control function. Brake system 17 includes two symmetrically designed brake circuits 19a, 19b in an X or II distribution pattern. Reference is thus made below only to part 19a shown on the left in Figure 1.

The brake system includes a brake pedal 1, a brake booster 2 to which is connected a main brake cylinder 4 on which is situated a brake fluid reservoir 3. Operating brake pedal 1 produces a pressure in main brake lines 5a, 5b which acts upon brake shoes 11 of wheels 12 via a changeover valve 8a and the two intake valves 10a, 10b. The path in which pressure builds up during the operation of brake pedal 1 is identified by arrow b. A high-pressure switching valve 7a is closed in this state.

Upon the intervention of the vehicle dynamics control system, the brake pressure is automatically built up and distributed to predetermined wheels 12. For this purpose, brake system 17 includes a hydraulic pump 9a, which is activated by a control unit (not illustrated). When regulation takes place, changeover valve 8a is closed and high-pressure switching valve 7a is usually opened. Hydraulic pump 9a then delivers the hydraulic fluid along path a to brake shoes 11. The hydraulic fluid thus flows out of brake fluid reservoir 3 and passes through main brake line 5a, high-pressure switching valve 7a, an intake line 6a, hydraulic pump 9a and on through intake valves 10a, 10b to brake shoes 11. The brake pressure is modulated by intake valves 10a, 10b and discharge valves 13a, 13b, short-term pressure peaks being temporarily stored in an equalizing tank 14a.

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To prevent equalizing tank 14a from overflowing, hydraulic pump 9a regularly pumps the excess brake fluid back toward brake fluid reservoir 3. High-pressure switching valve 7a is closed for this purpose. During the return transport of the brake fluid, intake line 6a of pump 9a may be evacuated. If the main stage of high-pressure valve 7a reopens in this state, the brake fluid flows abruptly into the evacuated space of intake line 6a. This process produces a very loud noise which is irritating to the driver (known as the pressure equalization knock) and a noticeable brake pedal movement, in particular if the admission pressure is in a range from approximately 10 bar to 50 bar.

High-pressure switching valve 7a is commonly designed in two stages, a first stage and a main stage, to enable valve 7 to be opened even at high differential pressures. The differential pressure present at switching valve 7a has a closing effect on the valve. Opening the first stage slightly decreases the differential pressure so that less energy is required to open the main stage.

High-pressure switching valve 7a is customarily driven by a pulse-width-modulated voltage signal (PWM signal). To ensure that valve 7a opens safely, in particular at high differential pressures, valve 7a is activated by a 100% PWM system for a period of approximately 20 ms at the beginning of the driving action. Figure 2a shows the variation of the PWM control signal in the case of the previous activation operation. PWM signal 20 subsequently drops, for example, to 60%, depending on the pressure, due to the thermal stressability of valve 7a (see section 23 of control signal 20). This type of activation frequently causes the main stage of switching valve 7 to open abruptly, thus resulting in the aforementioned pressure equalization knock.

Figure 2b shows the variation of the current flowing through a coil of the valve. Current drop 24 marks the point at which the first stage of the valve opens. The main stage opens immediately thereafter, resulting in the pressure equalization knock.

The object of the present invention is therefore to open a two-stage switching valve in such a manner that a pressure equalization knock does not occur or occurs only to a limited extent.

This object is achieved according to the present invention by the features stated in Claim 1. Further embodiments of the present invention are the subject of subclaims.

According to an important aspect of the present invention, the two-stage switching valve is activated in such a way that only the first stage opens during a first phase, and the main stage opens only after a predetermined period of time if a certain pressure compensation has occurred at the valve. To achieve this, the switching valve is activated, according to the present invention, by a low-level control signal during the first phase, this control signal initially opening only the first stage of the valve. After a predetermined period of time, the switching valve is then activated by a higher-level signal to ensure that the valve always opens completely (i.e., including the main stage). This two-stage activation delays the opening of the main stage, thus substantially reducing the pressure equalization knock.

The signal level during the first driving phase is preferably selected in such a way that the opening of the main stage of the switching valve is delayed by at least 10 ms, preferably by at least 30 ms. This allows a pressure compensation to occur at the valve, which reduces the pressure equalization knock.

According to a preferred embodiment of the present invention, the multi-stage activation operation is carried out only within a predetermined pressure range between, for example, 10 bar and 30 bar and, in particular, between 5 bar and 35 bar. For technical reasons, it is normally not possible to immediately open the main stage of the switching valve at pressures above 30 bar to 40 bar, even at maximum activation. Below 5 bar to 10 bar, the noise development and pedal feedback of the pressure equalization knock is already minimal. The pressure prevailing at the switching valve may be measured or estimated, for example using an admission pressure sensor.

The valve opening behavior is usually heavily dependent on voltage and temperature. The control signal for the valve is therefore preferably voltage- and/or temperature-compensated. For example, the voltage actually present at the valve may be measured and the coil temperature estimated.

The present invention is explained in greater detail below by way of example on the basis of the attached drawing:

Figure 1	shows a hydraulic brake system known from the related art;
Figure 2a	shows the variation of a control signal for a high-pressure switching valve according to the related art;

Figure 2b	shows the associated current variation in the coil of the high-pressure switching valve;
Figure 3a	shows the variation of the control signal according to an embodiment of the present invention;
Figure 3b	shows the associated current variation in the coil of the high-pressure switching valve;
Figure 4	shows the current variation for opening the first and main stages of the valve as a function of pressure; and
Figure 5	shows a flow chart of the main steps of a method for activating a high-pressure switching valve.

Reference is made to the preamble of the description for an explanation of Figures 1 through 2b.

Figure 3a shows the variation of a PWM control signal used to activate two-stage switching valve 7a, 7b, the first stage of the valve being opened first, and the main stage opening only after a predetermined delay period. Valve 7a, 7b is first activated by a PWM signal of, for example, 60%, and this level remains for a period of approximately 50 ms.

Figure 3b shows the associated current variation through the coil of valve 7a, 7b. After time t = 0, the current initially rises to a first level, where it remains during first phase A. A first current drop 24 after approximately 5 ms indicates the opening of the first stage. The pressure compensation that now takes place reduces the closing force acting upon the valve so that the main stage of valve 7a, 7b also opens automatically after approximately 40 s. Second current drop 25 indicates the opening of the main stage. After, for example, 50 ms, the PWM signal is increased to 100% (see section 21 of the signal) to ensure that valve 7a, 7b does indeed always open all the way. After approximately 20 ms, the signal level is decreased to a lower level 23 to avoid overheating the valve.

Alternatively, it would be possible to apply high signal level 21 even before the main stage opens automatically to force the main stage of valve 7a, 7b to open prematurely and to accelerate the opening of valve 7a, 7b. The corresponding signal variation is represented by dotted lines 26 and 27, respectively. The time at which the main stage opens should

preferably be at least 10 ms to 20 ms after the first stage opens to allow at least a slight pressure compensation to occur in the meantime at valve 7a, 7b.

Figure 4 shows the current of valve 7a, 7b that is required as a function of the admission pressure for opening the first or main stage. Line 30 marks the minimum current needed to open the first stage and line 31 the minimum current needed to open the main stage of valve 7a, 7b. As is apparent, the required minimum current increases as the admission pressure rises, since the pressure has a closing effect on the valve. Hatched area 32 marks the current range in which only the first stage of valve 7a, 7b is opened and which consequently is selectable for activation phase A.

Figure 5 shows the main steps in a method for activating a two-stage high-pressure switching valve 7a, 7b. The algorithm may be stored, for example, in a control unit (not illustrated). In a first step 40, a first check is carried out to determine whether the admission pressure present at valve 7a, 7b lies within a predetermined range, e.g., between 5 bar and 35 bar. For this purpose, the admission pressure is measured by admission pressure sensor 29 (see Figure 1) and compared with predetermined threshold values SW1, SW 2. If admission pressure p_{vor} lies within the predetermined pressure range (case J), instantaneous valve coil temperature T is estimated in step 41 (the temperature may also be measured). In step 42, valve 7a, 7b is then activated by a voltage- and temperature-compensated control signal 20 for a predetermined period of time, the control signal being of such magnitude that the first stage of valve 7a, 7b is opened, while the main stage remains closed for a predetermined period of at least 20 ms. In step 43, the control signal is then increased to ensure that the valve always opens all the way.

Activation of high-pressure switching valve 7a, 7b described above enables a pressure equalization knock to be substantially reduced.

List of reference numerals

1	Brake pedal
2	Power brake
3	Brake fluid reservoir
4	Main brake cylinder
5a, 5b	Main brake lines
6a, 6b	Intake line
7a, 7b	High-pressure switching valve
8a, 8b	Changeover valve
9a, 9b	Hydraulic pump
10a-10d	Intake valves
11	Brake shoes
12	Wheels
13a-13d	Discharge valves
14a, 14b	Equalizing tank
15a, 15b	Check valves
16	Engine
17	Brake system
18	Admission pressure sensor
19a, b	Brake circuits
20	PWM signal
21	High signal level
22	Low signal level
23	Low signal level
24	Opening of first stage
25	Opening of main stage
26	Premature opening of main stage
27	Low signal level
30	Minimum current for opening the first stage
31	Minimum current for opening the main stage
32	Intermediate current range
40-43	Method steps
A	First phase
B	Second phase
P_{vor}	Admission pressure